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SALIENT POINTS CONCERNING THE GLACIAL GEOLOGY OF NORTH GREENLAND.

CONTENTS.

Possibility of continuous glaciation between Greenland and adjacent lands.—The study of the west coast of Greenland raised, but did not settle, the question of the possibility of continuous glaciation from a land mass, such as Greenland, over an intervening body of water, such as Baffin Bay and Davis Strait, to another land mass, such as the continent of North America. While the idea that the North American ice of the glacial epoch had its center in Greenland is no longer tenable, it does not appear that the possibility of such a thing has been doubted.

Even a cursory inspection of the west coast of Greenland seemed to show clearly that ice has not overridden the entire

coastal region of the island in recent times, and perhaps never. So far as could be judged from topography in passing, it did not even seem probable that ice from the main island ever crossed the narrow Waigat so as to become continuous with that on the island of Disco, although both the coast of the mainland in this latitude and the main portion of the Disco coast appear to have been glaciated. The topography of the coast bordering the Waigat is such as to suggest that the east coast of Disco has been glaciated by ice moving to the eastward from the interior of the island, while the opposite coast of Greenland appears to have been affected by ice moving toward the westward.

The plateau of Greenland often terminates abruptly near the coast, with a precipitous face 1500 to 3000 feet in height. Between this abrupt bluff and the water, there is usually no more than a narrow strip of low land, and often none. Along those parts of the coast where the ice-cap comes out to the edge of the plateau, it fails to reach the water for any considerable stretch. It is true that the ice, where it now reaches the edge of the abruptly terminated plateau, generally reaches it with a slight thickness only ; but thick or thin, its edge breaks off and falls to the bottom of the cliff. Where the amount of ice breaking off and falling to the base of a cliff is great, it sometimes becomes re-united, and develops a small glacier. Such glaciers were seen both along the east side of Disco, and at various points on the coast of Greenland.

If the ice-cap on the upland were to advance more rapidly, or in greater mass, the amount of ice falling over the cliffs would be greater, and the glaciers formed at their bases would be correspondingly larger. It is conceivable that they might develop on such a scale as ultimately to become continuous with one another laterally. At the same time, by growth at their upper ends, they might become continuous with the ice-cap above. In this case the ice might move out from the interior over the coastal cliff without inflicting sufficient wear on the cliff face to greatly reduce its asperities, for the rough face would be to leeward. But it would not appear that such an ice-cap

on a plateau like that opposite the island of Disco could push out across a body of water like the Waigat, and overspread the island, without inflicting pronounced wear on the east bluff-face (stoss side) of that island. The freedom of the steep east side of Disco from such marks as the moving ice should have left, indicate that Greenland ice never surmounted it.

Further north in Whale Sound stands Herbert Island, distant but a few miles from the coast of Greenland to the south. For a considerable distance, the opposite coast of Greenland appears to have been glaciated, at some relatively recent time, by ice moving toward the coast; but the topography of the south face of Herbert Island gives no suggestion that the ice from the mainland ever reached it. The north face of Herbert Island likewise fronts a coast which may have been continuously glaciated, but there is nothing in the topography of the north face of the island, or so far as known in its drift, to indicate that ice from the north ever bridged the water which separates it from the land to the north. Other islands in similar relations might be mentioned, showing similar phenomena. Professor Chamberlin has called attention to the phenomena of Dalrymple Island,[1] and Cone Island (Fig. 1) near the entrance of Jones Sound is equally striking.

There are then in the northern waters small islands, and their number is considerable, lying near much larger bodies of land, which appear not to have been glaciated except by ice originating on themselves.

Along those parts of Greenland where the coast is less high and rugged, and where the main ice-cap reaches the edge of the upland, it does not push out to sea as a continuous sheet, but as a series of glaciers, separated from one another by high hills of the nunatak type, though not completely surrounded by ice. These ice-free mountains stand up several hundred, and in some cases one or two thousand, feet above the ice on either side. This shows that the valleys are sufficient avenues of discharge for the ice-sheet, as now developed. The amount of snow fall and ice

[1] JOUR. OF GEOL., Vol. II, p. 661.

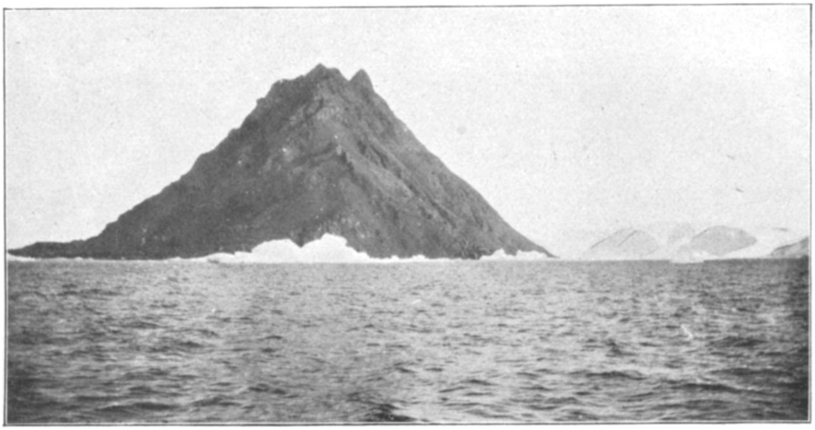

FIG. 1. Cone Island, Jones Sound, latitude 76° 20′, near Smith Island.

FIG. 2. A nunatak on the north side of Northumberland Island.

accumulation over the interior would need to be enormously increased before these elevations would be overridden by the ice moving out from the interior. The phenomena were such as to raise the question whether snow fall and ice accumulation could ever be so increased that the ice, moving from the interior to the coast, would override these border elevations so long as present topographic relations hold. Elevations 1000 feet high in the situations referred to would not be smothered by ice if the ice-sheet were thickened 1000 feet, since in that event the ice-drainage through the valleys would be greatly augmented, and would draw down the level of the ice immediately adjacent. It is believed that the ice-cap would need to be thickened several thousand feet before the coastal regions of the island would be completely covered.

The coast of Melville Bay is now suffering more nearly uninterrupted glaciation than any other portion of the coast seen. For a considerable distance east of Cape York it is true that three-fourths, possibly four-fifths, of the coast line is of land-ice at the present time. Yet the ice-cap lying back of Melville Bay would need to be enormously thickened in order to cover the fourth or fifth of land which is now bare.

The phenomenon of floating glacier ends, seen at several points, and heretofore referred to,[1] perhaps affords a clue to the way in which water intervals between land masses might be bridged by glacier ice, so far as they can be bridged at all. If the ice of the sea, formed by the freezing of the sea water, be not disrupted for long periods of time, the ends of glaciers crowding out into it, not being able to break off and float away as bergs, might at first float. As they advanced they might thicken, and if the water be sufficiently shallow they might ultimately rest on the bottom. With the ice of the surrounding seas still remaining unbroken, the forward movement of the ice from the land might urge the glacier ice in the water basin across the bottom of the same, and up on the opposing land. But it would seem well-nigh certain that, under the extreme conditions

[1] JOUR. OF GEOL., Vol. III, p. 875.

of climate necessary for this sequence of events, any land which the ice might invade after crossing a water interval would have an ice-cap of its own, and such an ice-cap, descending to its coasts, would come out to meet any ice-cap which might be approaching from other lands. It is conceivable that the ice-caps of adjacent lands might meet each other in the water interval now separating those lands. The line of meeting might not be midway between the two coasts, and one body of ice might have great advantage over the other. The ice of the one land mass might thus become continuous, in some sense, with the ice of another. But under these conditions all coasts would be to leeward of the ice passing over them, and the topography of leeward coasts should be recognizably different from that of stoss coasts.

The shallower the water between land masses, the easier would it be for ice from one land to bridge it and invade the other. Elevation of a region to the extent of the depth of the water intervening between two land masses, or even a little less, would obviate the difficulties in the way of continuous glaciation from the one to the other.

The phenomena of the islands of the coast of Greenland indicate that ice from the latter has not recently, if ever, overridden them. The phenomena of the Greenland coast indicate that thickening of the ice adequate even for the complete overriding of the coast has not taken place in recent times, if ever; and the phenomena, in the aggregate, raise a question as to the possibility of such overriding.

Glaciation across other bodies of water.—The same question was raised in Newfoundland. It has generally been assumed that the ice-cap from the mainland bridged the interval between Labrador and Newfoundland; but more recent studies of the glacial phenomena of the island suggest that its glaciation may have been entirely indigenous. This is the conclusion of Mr. James Howley, the geologist of the island, in spite of the fact that pieces both of labradorite and metallic copper have been found in the drift. The interior of the island is too imper-

fectly known to make it certain that both these materials may not be indigenous. It, of course, remains that the glaciation of Newfoundland may be local, without denying the possibility of the extension of ice from the mainland across even so narrow, though moderately deep, body of water as separates the island from the mainland.

Although affording no specific warrant for speculation concerning phenomena on the other side of the Atlantic, the phenomena about Greenland raise the inquiry whether continuity of glaciation from Scandinavia to the British Isles was really a fact. I am not familiar with the details of the evidence on which the current belief rests, but it seems to me difficult to believe that snow and ice could accumulate on so narrow a strip of land as Scandinavia in sufficient quantity to allow it to cross the North Sea to the British Isles, if relative elevations remained as they now are. If the water separation was much narrower and shallower than now (a result which an elevation of a few hundred feet would bring about) some of the difficulties would be obviated; but Geikie[1] finds reason for believing that the British Isles were, in general, lower than now during epochs of glaciation. Existing evidence on this point would be likely to pertain to the closing, rather than to the opening stages of an ice epoch. If the North Sea basin were overspread by a thick sheet of ice, the covering being accomplished when the land and the sea bottom were higher, a submergence considerably below the present level might be necessary to sever the continental from the island part of the ice-sheet.

Is it not true that something more than the presence of Scandinavian bowlders in Great Britain is necessary to prove continuous glaciation between these two lands? Submergence, with floating ice, might land such bowlders in Great Britain and Ireland, and they might subsequently be incorporated into till by indigenous glaciation. If there be shells in the till of Scotland which came from the bottom of the North Sea, they would seem to be good evidence of continuous glaciation across this sea

[1] Great Ice Age, 3d edition.

from the north. But may not the shells which are found be accounted for in some other way? The real question is, not how the shells in the till might have reached their present position, but how they did reach it. If Great Britain was glaciated

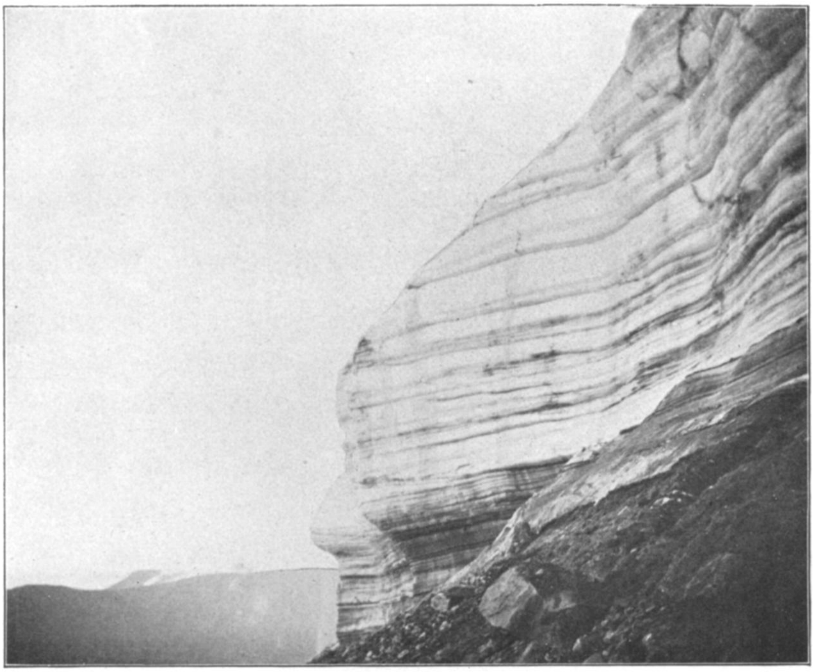

FIG. 3.—Profile of end of a glacier, near the head of McCormick Bay.

by ice from the northeast, its eastern and northern coasts should show the topographic features which characterize the stoss side of a land mass. The application of this criterion might be difficult, since the supposed continuity of glaciation is referred to the earlier ice epochs, the work of which has been obscured or obliterated by later glaciations, as well as by other processes. It is meant here simply to raise the question whether the evidence for continuous glaciation from Scandinavia to Great Britain does not need re-examination. Are the phenomena such as to preclude other explanations?

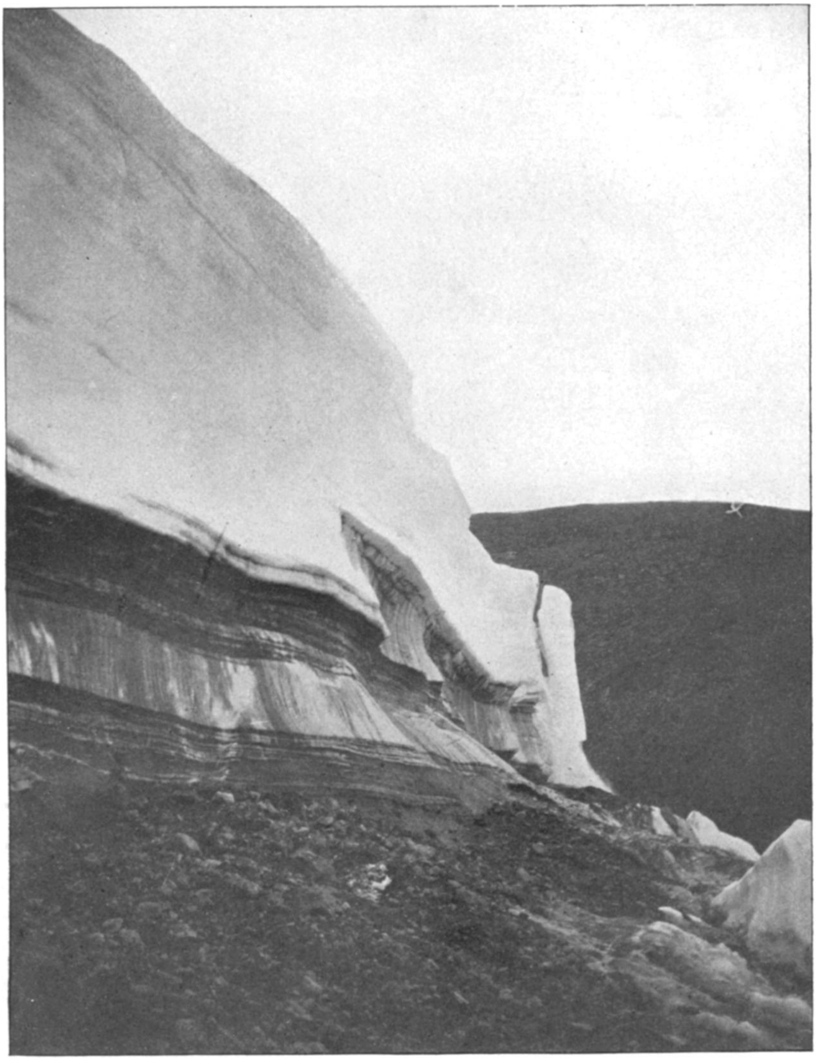

FIG. 4.—Side of Gable glacier near its end. East side of Bowdoin Bay.

Steep faces of glaciers.—Professor Chamberlin has repeatedly called attention to the remarkably steep faces of the average glacier in the high latitudes of the west coast of Greenland[1] (see Figs. 3, 4, 5, 6, 7, 10, and 11). I was fortunate enough to see many glaciers which Professor Chamberlin did not, and his generalization was confirmed by the facts gathered from other sources. Steep, and even vertical, faces frequently affect both the ends and the sides of the glaciers. It is not true, however, that the sides and ends of all glaciers in the high latitudes of Greenland are vertical or approximately so, though this is the general rule north of Cape York. In many cases, instead of having vertical faces, the ends and sides of glaciers slope down to the bed of the ice by steep convex curves (Figs. 6 and 7). These slopes are usually so steep as to make ascent or descent difficult, and often impossible. In a few cases only, so few as to make them conspicuous, the slopes both of ends and sides are so gentle as to allow ready ascent. In some of these cases, if not in all, the low angle was due to the exceptional accumulation of drifted snow (Fig. 8) about the borders of the glacier proper. This drifted snow had become consolidated into granular ice, so that the glacier proper had really received an addition all around its margin, giving it gentle slopes.

The phenomena of the edges and ends of the glaciers are in keeping with the phenomena of the edge of the ice-cap itself. Where the latter lies on a plain surface, its edge is not usually vertical, but its slope is so steep that ascent is difficult (Figs. 6, 8, 9). It will be seen from the figures that the angle of slope near the edge is high, but becomes rapidly less with increasing distance from the margin. Only where snow has drifted against the edge of the ice-cap, as it has done in many places, forming an extensive foot, (Fig. 8) is the slope of its edge gentle enough to make ascent comfortable at any point where it was seen.

Overhanging layers of ice.—Not only are the edges and ends

[1] Glacial Studies in Greenland, Vols. II, III, and IV, of this Journal.

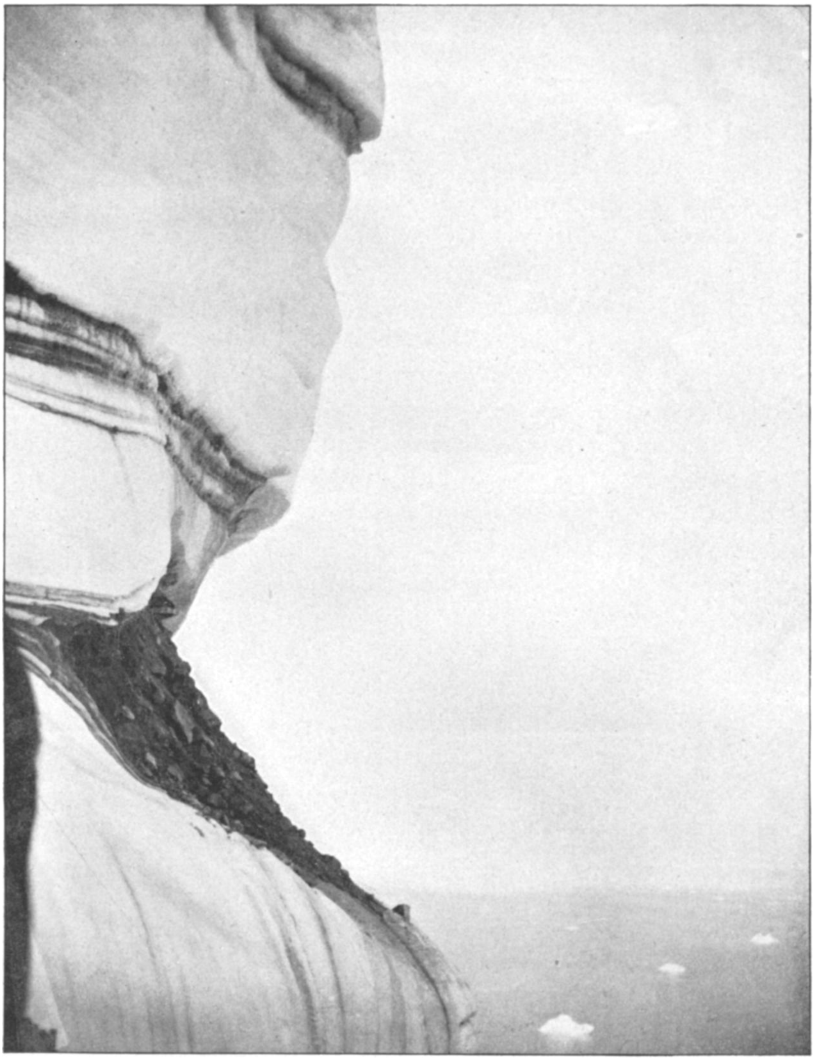

FIG. 5.—Profile of a portion of the side of a glacier on the north side of Herbert Island.

of the glaciers in many cases approximately vertical, but the higher parts often overhang the lower (Figs. 3, 4, and 5). The overhang is of different types. In general it seems to be true that the overhang is dependent upon something in the structure or constitution of the ice. (1) Where the ice is made up of layers of unequal firmness, the more compact layers are likely to project out over the more granular layers beneath (Fig. 3). (2) Where there are layers of débris in the ice, the ice immediately above is likely to overhang the débris-bearing layer (Figs. 4 and 5). The overhang is usually the more pronounced the larger the amount of débris. Since the lower fourth, third, or half of the ends and edges of glaciers, as seen in section, is often full of débris, the upper half, two-thirds, or three-fourths, often overhangs the lower portion, as shown in Fig. 10.

Where the débris is in very thin zones between thin layers of ice, the overhang sometimes takes on a different phase. Here the appearance is such as to suggest that a given layer of ice has been shoved out a little over the next underlying (Fig. 11). On close examination of the ice where the photograph reproduced in Fig. 11 was taken, it was found in every case where one layer appeared to have shoved out over its subjacent neighbor, that the junction between the two was marked by a thin zone (or film) of débris. In some cases the overhang, after persisting laterally for some feet, ceased for the space of a foot or two or more (see Fig. 12), to be continued again beyond. This was sometimes repeated frequently along the contact of the layers. If the phenomenon in question were really the result of the shoving of an upper layer of ice over the one beneath, it would hardly be true that the movement would fail for a few inches (as at *bc*, *de*, *fg*, etc., Fig. 12) at frequent intervals. On cutting back into the face of the ice where this phenomenon of interrupted overhang was seen, it was found, in every case where the point was tested, that where the overhang failed, the débris between the layers also failed, and that the amount of overhang all along was in a general way proportional to the amount of débris.

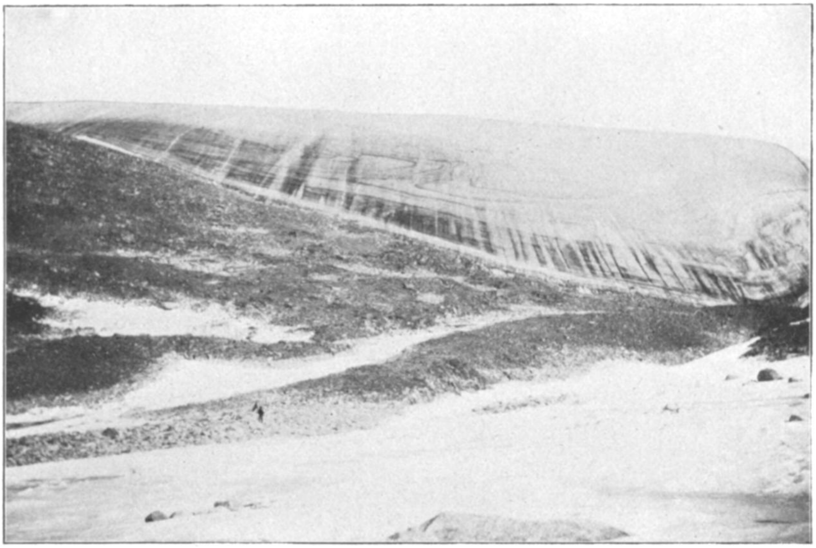

FIG. 6.—A broad but very short glacial lobe from a local ice-cap near "Meteor" Bay, east of Cape York.

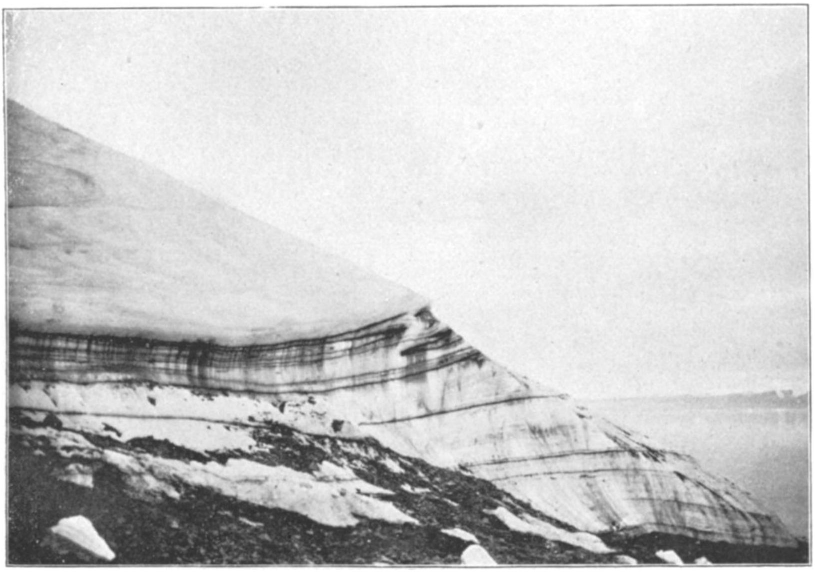

FIG. 7.—Profile of end of a glacier on north side of Herbert Island.

These relations led to the conclusion that the overhang in this, as in other cases, was the result of unequal melting, due to the unequal distribution of débris. The débris, being dark colored, absorbs the heat to a greater extent than the clean ice, and the ice behind the débris is therefore melted back more rapidly. As the thin zone which carries the débris is melted back, the water trickling down the face of the ice below carries the earthy matter with it. The ice just below the débris zone is coated with the finer materials washed down, and for this reason is melted back more rapidly than clean ice, and most rapidly where the coating is thickest. This causes the layer just below the débris zone to be melted back, on the whole, faster than the layer above, and to recede most rapidly at the débris level. This gives rise to the phenomena seen in Fig. 11.

Stratification and veining of the ice.—One of the conspicuous features of the ice of north Greenland is its distinct and often very conspicuous stratification (see Figs. 3–7 and 11), though there is much arrangement in layers which is not stratification, in the proper sense of the term. The layers (and veins) may be horizontal or vertical, or inclined at any angle. The arrangement of the vertical layers (veins) may be longitudinal or transverse, with reference to the glacier.

The presence of débris between the horizontal or approximately horizontal layers often helps to emphasize their distinctness, but their existence is not the result of the presence of débris. Certain layers of the ice are more solid (and blue), and certain other layers are more porous (and white). It is upon the varying texture of the different layers that the stratification in the upper part of a glacier is usually dependent, while the débris often emphasizes the distinctness of the layers in the lower portion. The horizontal layers or laminæ of ice are of variable thickness, and it would appear that the melting of ice, like the weathering of rock, often develops laminæ within layers which, in a firmer condition, appear massive. The number of laminæ is often as much as eight or ten to the inch, at the same time that layers several feet in thickness do not, in a solid con-

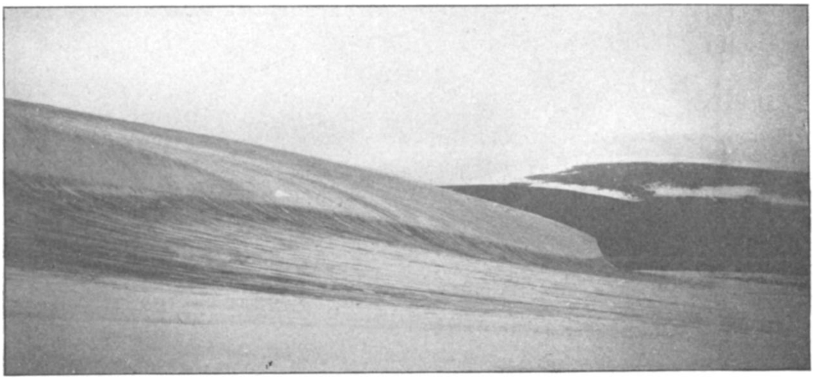

FIG. 8.—Edge of the local ice-cap on the peninsula between Bowdoin Bay and Inglefield Gulf. The low slope of the ice in the foreground is due to snow.

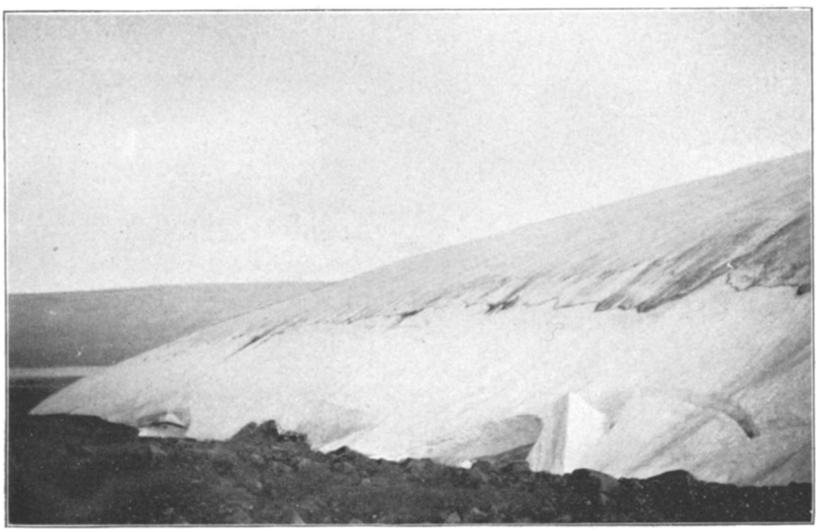

FIG. 9.—Edge of the local ice-cap north of Olriks Bay. The lower slope is snow.

dition, show conspicuous division. The horizontality of the layers is often interfered with at or near the ends of glaciers, and also at and near their lateral margins. This will be referred to later.

The vertical arrangement of layers appears to belong to the

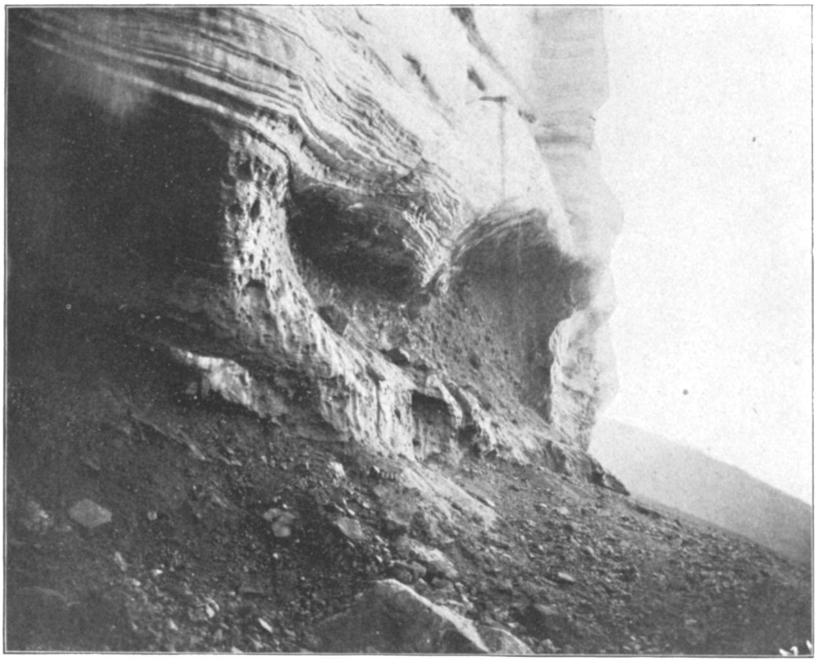

FIG. 10.—Edge of a glacier on the southeast side of McCormick Bay, showing effect of débris on overhang.

category of veining, rather than stratification. The vertical veins appear to be altogether absent in many glaciers, and to be present in portions only of many others. Their presence or absence did not appear to depend upon any condition which affected the differentiated portion of the glacier. Indeed, if there are significant differences between the surroundings of glaciers which have vertical-longitudinal veins and those which have not, it was not discovered. The vertical-longitudinal veins were not seen in a

large proportion of the glaciers visited. Where present, they sometimes showed themselves on the surface of the ice, so that in crossing the glacier, lining parallel to its axis was conspicuous. The lining was often emphasized by the fact that certain

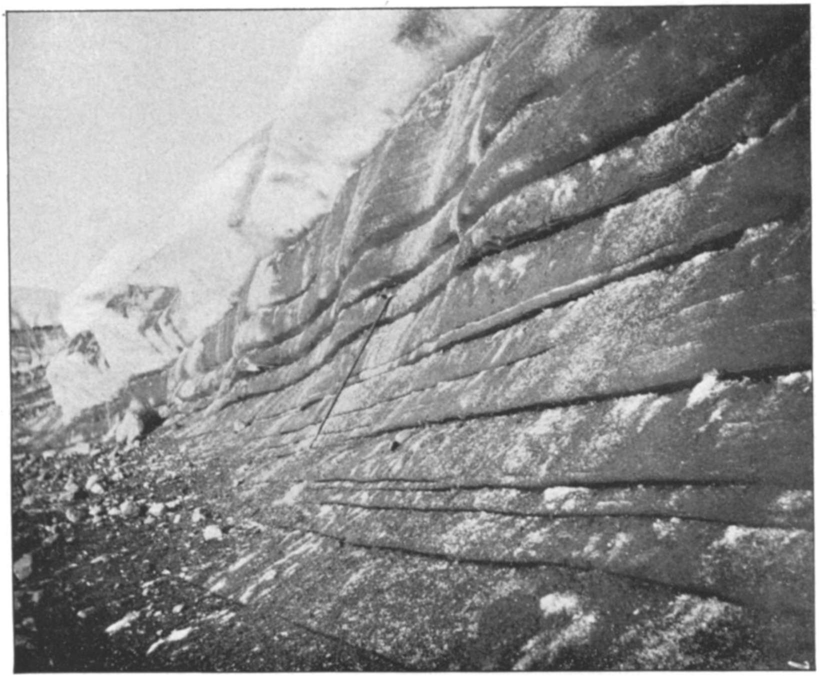

FIG. 11.—Edge of Tooktoo glacier, next a nunatak separating it from the Bowdoin glacier. A few miles above the head of Bowdoin Bay.

veins, presumably of less compact ice, melted more readily than others, thus developing grooves, between which the edges of the more resistant layers stood out as ridges. These vertical-longitudinal veins are of various thicknesses, but usually less than an inch. In some glaciers, notably in the western glacier of the north side of Herbert Island, there was a double ribbing of the surface, as shown in the accompanying diagram (Fig. 13). The larger swell or ridge, made up of many minor ones with their intervening grooves, seemed to be due, in some cases, to the

fact that the more solid veins composing it were thicker, and the less solid ones thinner, than in the troughs which lay beside them.

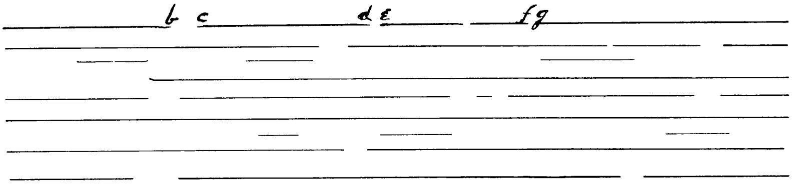

FIG. 12.—Diagrams showing how the overhangs, such as shown in Fig. 11, are interrupted laterally. The lines represent overhangs, and the interruptions represent the disappearance of the overhangs.

FIG. 13.— Diagram showing transverse profile of a small portion of the surface of the westernmost glacier on the north side of Herbert Island.

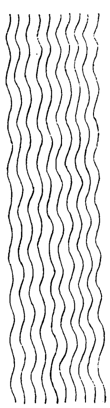

FIG. 14.—Diagram showing the wavy or sinuous course of the outcropping edge of longitudinal vertical laminæ. Same glacier as Fig. 13.

In some places these vertical ribbings on the surface were far from straight. Occasionally, as on one of the glaciers on Herbert Island, they were distinctly wavy, as shown in Fig. 14. In two cases the vertical veining was seen at the ends of glaciers, where their faces were vertical. In these sections the outcropping edges of the veins were not straight in a vertical sense. Indeed they were sometimes sharply flexed.

Vertical veins transverse to the axis of the glacier, and therefore at right angles to the series just described, were seen in several places. They affect some glaciers where the longitudinal set is wanting, and some where it is present. The two sets of vertical veins may be in different portions of the same glacier, or they may affect the same part. Where seen, the longitudinal veins were thinner than the transverse, and more continuously present.

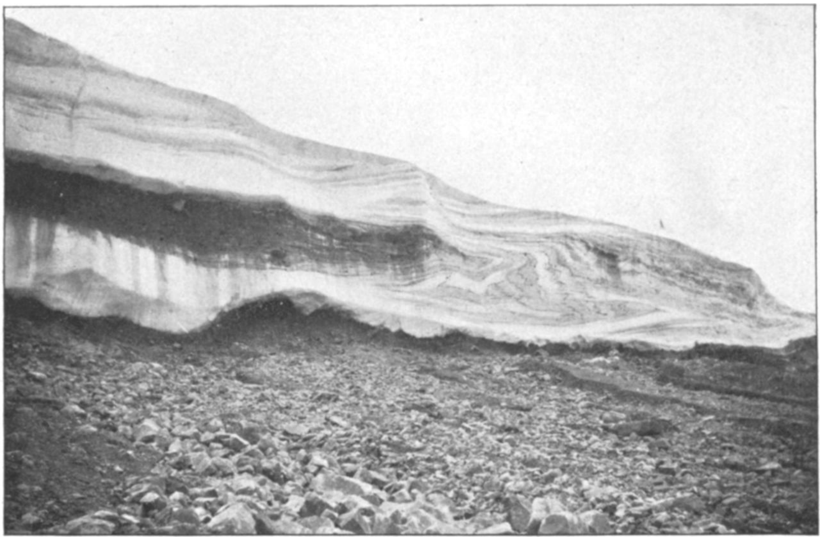

FIG. 15.—Contorted laminæ of ice in front of a lens of débris in the ice. Side of a glacier on the southeast side of McCormick Bay.

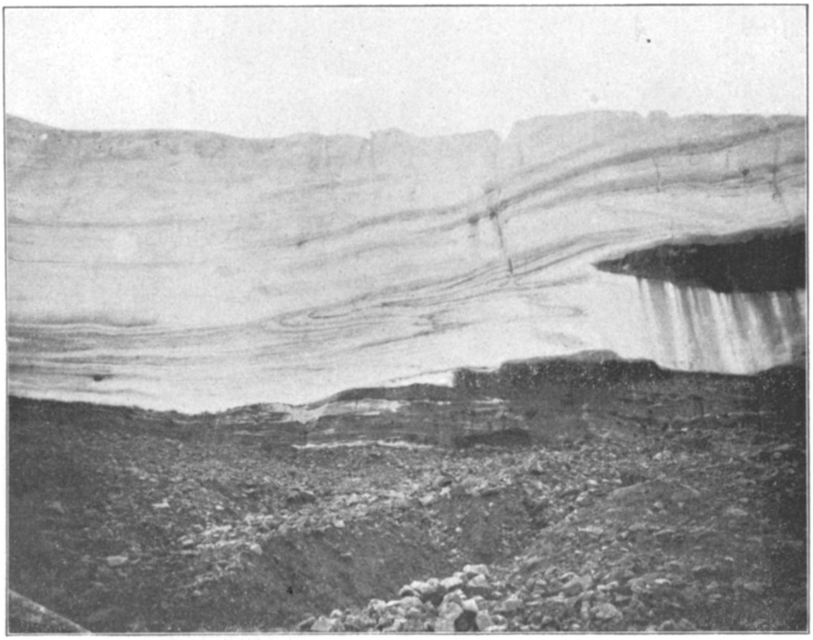

FIG. 16.— The other end of the same lens of débris as shown in Fig. 15.

The transverse veins appeared to belong to more than one category. In some cases they seemed very much like the longitudinal veins, while in other cases they seemed to be comparable to dikes. In places, these dike-like veins were as much as three or four feet thick. Locally they were of compact blue ice near their front and back walls, while the central portion was notably more granular. On the melting surface this resulted in a little ridge on either margin of the vein, with a slight depression in the center. Where a superglacial stream cut an ice gorge across one of these dike-like veins, it was often seen that the vein (or at least its walls) was of ice which was distinctly harder (and bluer) than that on either hand. As a result of its superior hardness, a rapids or waterfall was developed just below the vein, and there was a tendency to ponding above, just as in the case of a young stream cutting across a hard, vertical layer of rock. The transverse-vertical veins were nowhere seen to be contorted, or to present notably wavy outcrops at the surface.

Contortion of the layers and laminæ.— Professor Chamberlin has already called attention to the contortion of the laminæ in the Greenland ice. In the glaciers which I saw, contortion of laminæ seems to have been less general than in the glaciers seen by him. Indeed, most of the glaciers seen showed no considerable amount of contortion of laminæ, though in some cases the phenomenon was conspicuous. Its presence or absence seemed to be dependent upon certain relations, some of which at least were easily made out.

The horizontal laminæ are likely to be contorted about the considerable lenses or masses of débris which are occasionally incorporated in the body of the ice. This is shown in Fig. 15, which represents a frequently repeated relationship. Great masses or lenses of débris were rarely seen in the vertical face of a glacier, without contortion of laminæ, both behind and before, though the laminæ of ice above and below were not usually affected by contortion.

A second position in which the contortion of horizontal layers is common, is at the very base of the upper, clean part of the

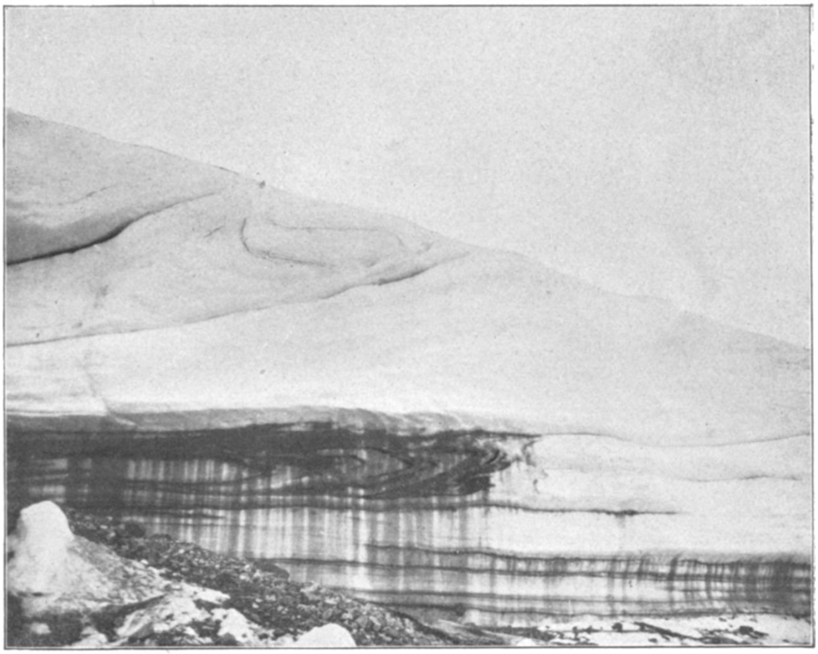

FIG. 17.— The laminæ of ice in the upturned and thickened layers are somewhat contorted. Herbert Island.

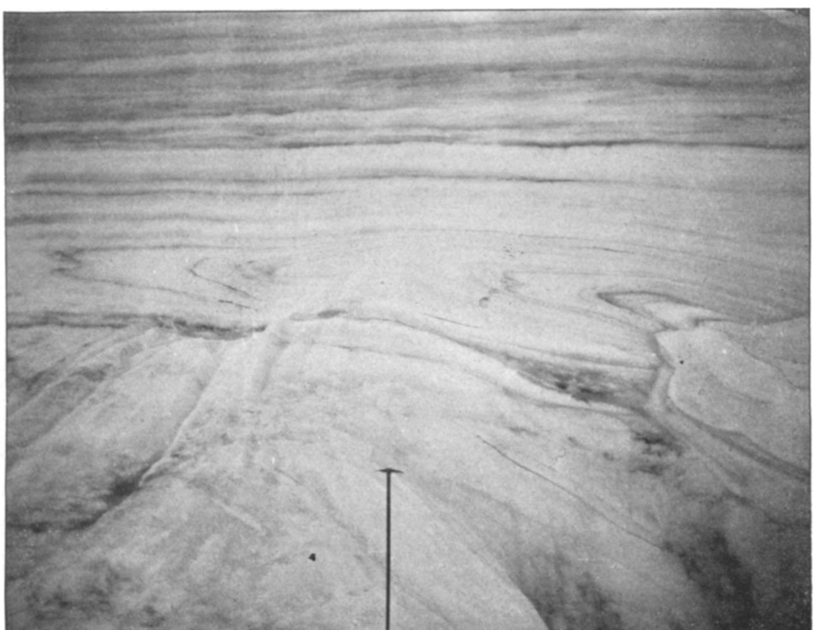

FIG. 18.— Contorted laminæ of clean or nearly clean ice. Glacier on the south side of Olriks Bay.

ice, just above its junction with the débris-charged portion below. In such cases, where a vertical section was exposed which really showed the structure of the ice, contortion was the almost universal rule.

In a few places the contortion of laminæ was seen to be

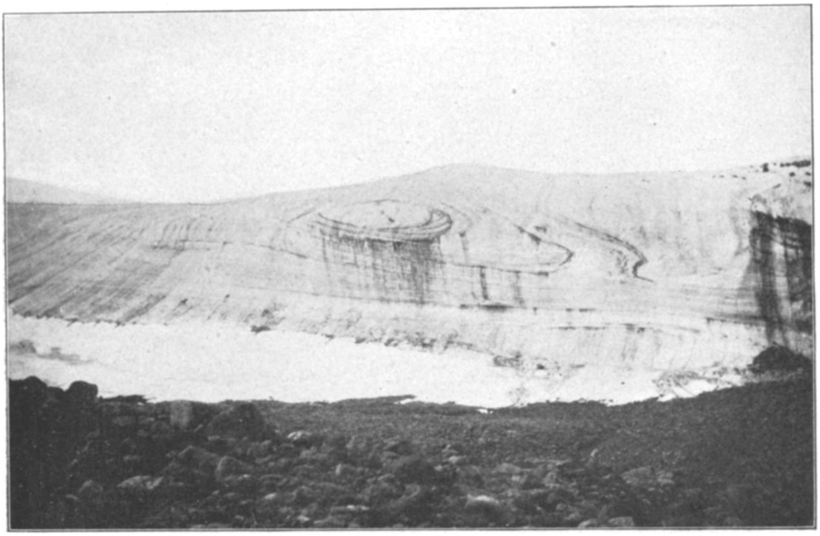

FIG. 19.— Structure resembling concretionary forms. Glacier on south side of Olriks Bay, west of the last.

striking where débris was absent, or where but little was present. This, however, is the exception rather than the rule (Figs. 17 and 18). Such a case is indicated in Fig. 6, which represents a sort of fœtal glacier — a tiny lobe projecting out from the edge of the ice-cap in the vicinity of Meteor Bay, some twenty-five or thirty miles northeast of Cape York. Attention is especially called to the position of the contortions, a position which is well-nigh universal. The bends are such as to suggest that the upper layers are crowding on faster than the lower. In a single case, only, were the contortions seen to lie in the opposite position, and this was on the opposite side of the same lobe.

The upturning of the layers of ice.—One of the striking phe-

nomena of the Greenland glaciers is the upturning of the horizontal layers at the ends and sides of glaciers. The upturning is most conspicuous as a rule at the extreme end. It becomes less and less striking with increasing distance from the end, and is not apparent at any considerable distance above. At the extreme ends of glaciers the upturning was seen to vary from a few degrees to verticality. An upturning of 30° or 40° was by no means uncommon. Higher inclinations were less frequent, and in but a single situation, namely in a glacier on the south of Olriks Bay (Figs. 20 and 21), was verticality attained. Figs. 20 and 21 represent a vertical face of ice at the end of a glacier, but the face is parallel to the axis of the glacier, not transverse to it. The same phenomenon in the same relations may frequently be seen at the sides of the glaciers. Fig. 22 shows the positions of the layers at the lateral margin of a glacier near Karnah. The layers are turned up most conspicuously at the extreme edges, and less and less markedly with increasing distance from them. So closely is the upturning confined to the lateral margins that the larger part of the surface of a glacier, even one where the lateral upturning is extreme, shows nothing of it. The upturning at the sides of a glacier is rarely equal to that at the end.

The lateral upturning is best seen at the vertical ends of glaciers. The following diagram (Fig. 23) may almost be said to represent the normal structure of a small glacier, as seen from its vertical end. If the glacier be a large one the structure shown is more likely to be that indicated diagrammatically in Fig. 24. The number of anticlines and synclines seen in cross-section in a large glacier may be several.

The upturning of the ends and edges of layers is not confined to differentiated glaciers, but affects the edge of the ice-cap as well. The edges of the main or local ice-caps were crossed in all at nine points. In seven of the nine, the marginal upturning of the layers was markedly developed. Generally speaking, it was most conspicuous where the visible amount of débris was greatest, and least where the débris was

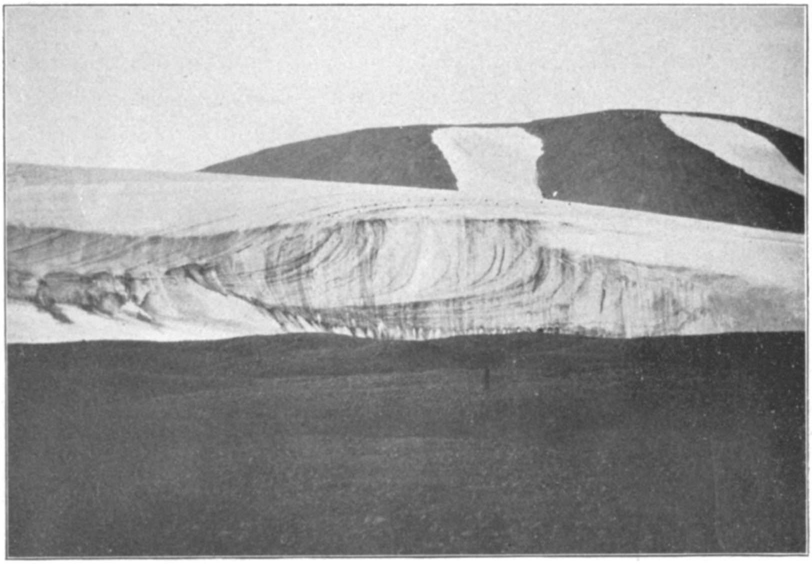

FIG. 20.—Vertical face of a glacier south side of Olriks Bay. The section is parallel with the axis of the glacier near the middle of its end. The dots on the surface are stones, lying along the outcropping edge of a layer.

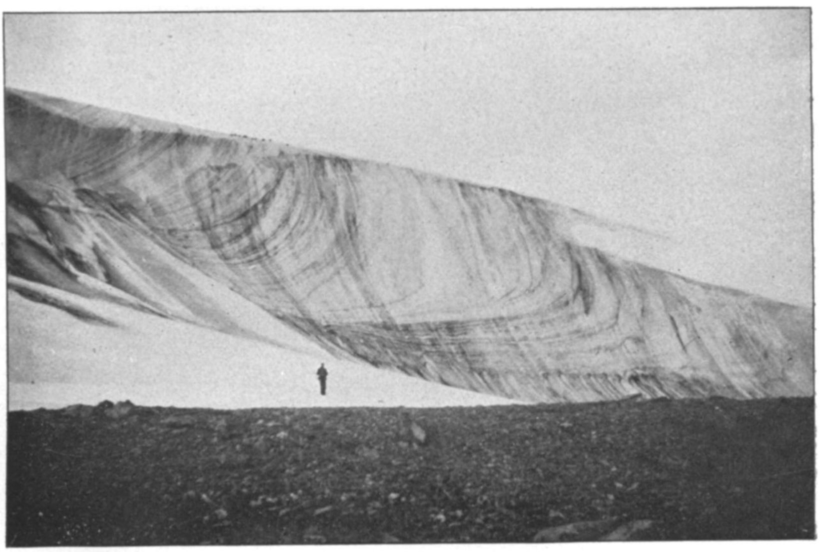

FIG. 21.—Enlarged view of a portion of 20.

absent or meager. It was not always clear, however, which was cause and which effect. On the whole it seems probable that each helped the other.

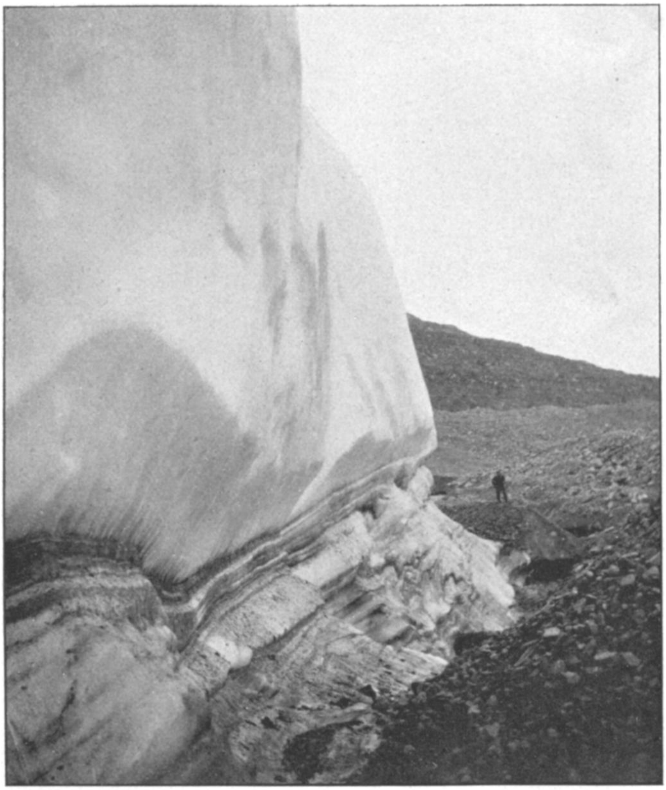

FIG. 22.—Showing the inward dip of layers of ice at the side of a glacier on Redcliff peninsula, above the settlement of Karnah.

Upturning layers of ice and superglacial débris.—The upturning of the layers of ice at the ends and edges of glaciers is often made especially obtrusive by the existence of well-defined layers of débris between them. As the upturned edges are melted, the débris in or between them accumulates on the surface of the ice along the line of outcrop of the débris zone. A small

amount of débris is shown in Fig. 20 along the line where one of the upturned layers reaches the surface. Where the débris in or between upturning layers is abundant, it is often accumulated in large quantities on the surface of the ice along the line of outcrop of the débris-bearing layer. This seems to

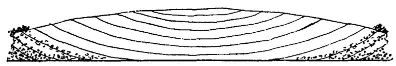

FIG. 23.--Diagram showing the structure of a small glacier as seen from its vertical end.

necessitate the conclusion that the drift is carried up to the surface by the upward movement of the upturned layers.

If the débris in a layer of ice, or between any two layers, were equal in amount at all points, it would appear at the surface in a continuous line or belt of drift, equal at all points. Its abundance would be dependent on the abundance of débris in the layer concerned, and on the length of time it had been bringing débris to the surface. In the course of time a very considerable ridge of drift might accumulate at the surface.

On the other hand, if the débris in or between layers of ice be more abundant at some points than at others, the accumulation on the surface would be in the form of an unequal, or possibly even a discontinuous ridge, more massive where the débris brought up is abundant, less massive where it is meager, and absent where it fails altogether. The same general rela-

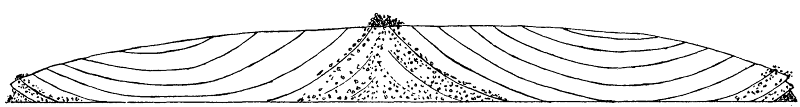

FIG. 24.—Diagrammatic representation of the structure of a large glacier as seen from its vertical end.

tions would hold concerning the upturning of the layers along the lateral margins of a glacier as along its end.

Phenomena illustrating these points were seen in many localities, both on the ice-cap itself, and on differentiated

glaciers. The edge of the ice-cap a few miles west of the upper end of Hubbard glacier showed the phenomena here referred to in simple form. Here the layers of ice at the edge of the ice-cap were upturned sharply. Between them, or between some

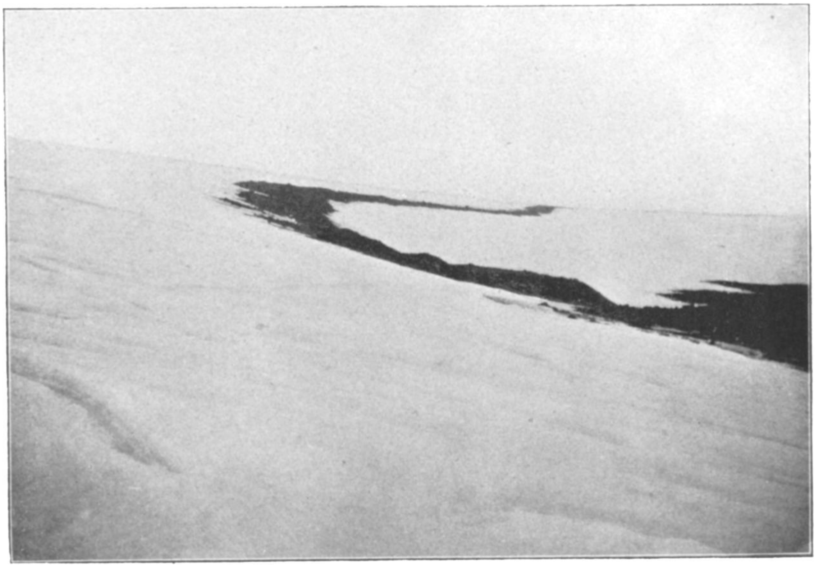

FIG. 25.—A ridge of superficial débris accumulated on the surface of the ice where an upturned layer reaches the surface. Edge of main ice-cap west of Hubbard glacier, Inglefield Gulf.

of them, there was débris, usually small in amount. The lines of outcrop of the débris-bearing zones were clearly marked on the surface of the ice-cap by nearly continuous lines of débris (Fig. 26). These lines were very unequal. The amount of drift coming up was much greater at some points than at others, and here the drift on the surface was piled up into very considerable mounds. Fig. 27 represents one of these mounds, something like thirty feet high, but it is probable that some portion of this elevation is due to a core of ice which is protected from melting by the drift which caps it.

Further west, and but a few miles east of Gable glacier,

where the main ice-sheet approaches the local ice-cap of the peninsula between Bowdoin Bay and Inglefield Gulf, the edge of the former shows similar phenomena on a much more extensive scale. Here drift comes up to the surface, not between all adjacent layers of ice, but only between certain layers. The

FIG. 26.--Belts of débris on the edge of the ice-cap west of Hubbard glacier. Each belt is confined strictly to the line of outcrop of an upturned débris-bearing layer.

larger part of it is in five distinct zones, which mark the outcrops of as many débris-charged horizons of ice. Each one of these belts of drift is irregular, here higher, there lower, so that each belt, instead of being a continuous and even-crested ridge of drift, is really a succession of mounds. Where the mounds attain considerable proportions, the drift spreads from their bases, so that high mounds are also always wide. Where two adjacent belts of drift are both irregular, it frequently happens that the mounds along one belt spread to such an extent that their bases are confluent with the bases of the mounds of the other belt.

These phenomena, repeated for all five belts of drift, gave rise to a peculiar and suggestive disposition of débris on the surface of the ice. Where the five belts approach each other so closely that the spreading drift of one becomes confluent with that of those adjacent, the surface of the ice for considerable areas

is completely concealed. Where this happens, the topography of the superficial drift reproduces, in all essential respects, the topography of the rough terminal moraines of the United States. Between adjacent hillocks or short ridges there are round, irregular, or elongate depressions, with sides often as steep as the

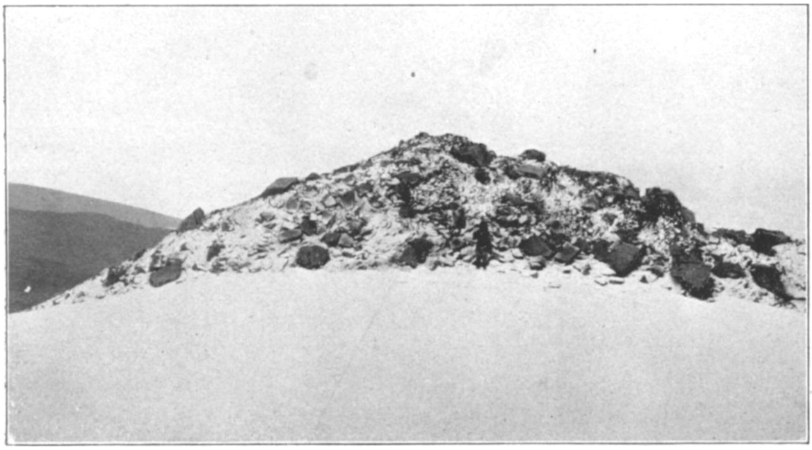

FIG. 27.—Mound of débris on edge of ice-cap near Hubbard glacier. It represents an exceptional accumulation of débris at one point, along the line where an upturning layer outcrops.

material will lie. The swells between the depressions are correspondingly abrupt. In its general contours, as well as in the specific relations of the elements of its topography, the surface drift of this locality is so like that of the terminal moraines of the United States as to suggest that, in the phenomena shown on the ice-cap at this and other points, is to be found the explanation of at least a part of the roughness of topography which characterizes terminal moraines in general. It is probably true that if the ice within the area here mentioned were to melt, depositing the drift on the surface beneath, its topography would be less rough than it is now, for it is probable that some considerable part of the elevations which appear to be of drift is really due to cores of concealed ice.

The phenomena shown on the ice-cap east of Gable glacier were shown to a less extent at various other points along the edge of the ice-cap in the vicinity of Inglefield Gulf, but best of all in the vicinity of Uminooi, latitude 76° 30′ (approximately). Here the edge of the main ice-cap was seen where there were eight of these marginal ridges of drift on the ice, sometimes separated by intervals of twenty or thirty rods, sometimes closely approaching each other. They were all gathered within a narrow marginal zone, the inner edge of which was not more than half a mile from the edge of the ice. The higher the angle of slope of the ice, the more closely did the belts of drift approach each other; the gentler the slope, the more widely were they separated. As in the locality north of Inglefield Gulf, each of these belts of drift was exceedingly irregular, being made up of a succession of hillocks, and short, or sometimes rather long, ridges, between which were depressions. Three of the depressions seen in this locality contained ponds or lakelets, one of which was fully 200 yards across. The existence of ponds in the depressions in the surface of the superglacial drift tended still further to emphasize the likeness of its topography to the topography of terminal moraines.

In this locality a single superglacial stream was found cutting through some of the belts of drift in such wise as to expose a shallow, though otherwise perfect section of the upper part of the ice below one of the belts of drift. The phenomena shown in the sides of the the little gorge are illustrated by the accompanying diagram (Fig. 28). The layers of ice beneath the drift turned up abruptly. In their upturning and movement they had brought débris to the surface, and as the ice melted this débris had accumulated on the surface, forming a ridge of drift. This ridge of drift had protected the ice beneath from melting, so that the upturned layers of ice, apart from the drift, constituted a diminutive ridge. That there was upward movement of the highly inclined layers seemed certain, not only from the relations of the débris, but from the bending of the adjacent horizontal layers.

The juxtaposition of the highly inclined and approximately horizontal layers, as shown in the figure, is explained as follows: In recent years the snow fall has exceeded the melting. Of this there was abundant evidence. Just before this condition of

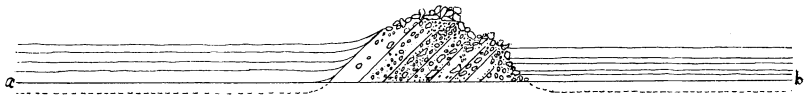

FIG. 28. Diagram showing longitudinal section of ice, as shown in the wall of the canyon of a superficial stream where the latter crossed a surface moraine.

things came about, melting had exceeded accumulation. The surface of the ice had been lowered, but the drift had protected the ice immediately beneath it, so as to give origin to a low ice ridge beneath the drift along the line of débris. It is believed that, at this stage, all the layers of ice near the edge of the ice-sheet were upturned, as they are now believed to be a little below the surface. The theoretical condition of things before the heavy snows of recent years is illustrated by Fig. 29. Later, when the snow fall exceeded the melting, the falling and accumulating snow was transformed into horizontal, or nearly horizontal, layers of ice (or névé), where it rested on ice. The drift, because of its heat absorbing qualities, helped to melt the snow which fell upon it, and its surface being elevated above that on either hand, allowed the snow to be blown off more than from the surrounding surface.

FIG. 29. Hypothetical profile of surface of Fig. 28 before the development of the overlying horizontal layers.

The drift phenomena shown on the edge of the ice-cap in association with the upturned layers, was repeated in many cases on glaciers, on the surfaces of which the upturning layers of ice had given origin to irregular and discontinuous ridges of drift.

These ridges were always near the ends of glaciers, and usually concentric with their termini, where the termini were not cut off by the waves. The surface ridges of débris, concentric with the ends of glaciers, were especially conspicuous on some of the glaciers on the north side of Northumberland Island, and on the glacier at the head of Dexterity Harbor, on the west side of Baffin Bay (Lat. 72°).

The making of lateral moraines.—Many of the North Greenland glaciers carry lateral moraines, the explanation of which is certainly to be found along the lines just indicated. In general the lateral margins of the glaciers do not touch the sides of the valleys in which they lie. Indeed they are generally separated from them by distinct intervals, and this holds well up to the heads of the glaciers. Within the stretch where the lateral margins of the glaciers do not touch the valley walls, lateral moraines have their least development near the heads of glaciers, where they are often absent, and their greatest near their lower ends. The lateral moraines, therefore, could not have been formed by the falling of débris from the valley slopes onto the ice, for of this there is no possibility. The upturning layers, as seen in cross-section, and the débris seen between these layers (Fig. 23), seem to show conclusively that the lateral moraines were formed by having material brought to the surface by the upturning and up-moving layers of ice. In some cases three of these lateral moraines lay side by side near the margin of a glacier, though more than two were rare. This statement is not to be construed to mean that this is the only way in which lateral moraines are made, but it seemed to be the prevalent way in the case of the glaciers seen in north Greenland.

Glacier load and its relations to movement.—Professor Russell[1] has called attention to the fact that the movement of ice is influenced by the amount of débris which it carries. This doctrine finds abundant confirmation in the north. The lower part of the ice, which is well charged with débris, or altogether full of it, seems to virtually lose its motion and to become the

[1] This JOURNAL, Vol. III, p. 823.

bed over which the upper ice passes. It is not possible to say that its motion is absolutely lost, but many phenomena seem to make it certain that the upper portion of the ice of a glacier passes over the lower débris-charged portion in the same way

FIG. 30.—End of a glacier on southeast side of McCormick Bay, resting on its embankment.

that it passes over a rock bed. The lower part of the ice in such cases becomes virtually an ice conglomerate, the mobility of which is certainly slight.

Morainic embankments.—The ends of many of the north Greenland glaciers appear to rest on huge embankments (or pedestals, as Chamberlin has called them) of drift, which they have constructed for themselves. The phenomenon is shown in Fig. 30. In reality these pedestals or embankments of drift on which the ends of many of the glaciers seem to rest, are less extensive than they seem. In many cases they appear to be 100

or 200 feet high, and, in extreme cases, as much as 300 feet. In the case of several glaciers, however, phenomena were seen which seem to throw doubt on the conclusion which at first sight seemed obvious. Where considerable streams plunge over the vertical faces of the glaciers, and cut gorges in this apparent embankment, it is now and then seen that the embankment is, after all, not composed entirely of drift, but that it is really glacier ice so full of débris that it has practically lost its motion, and that its outer surface only is coated with drift, free from ice. It is readily seen how this coating would be a necessity. As the débris-charged ice melts on the exterior, the débris which it held is loosened, and if the face of the ice be steep, slides down and comes to rest at such an angle as it is capable of assuming. If this process be carried on for a long period of time, the result is such as to give the impression of a great morainic embankment, when in reality much of the apparent embankment is ice, full of débris. In some sense, however, it is not wrong to look upon this apparent embankment of drift as really such, for were the ice in it to melt, a great embankment would still remain, but little less in height in some cases than it now appears; for the ice is often so full of débris that it comes to occupy only the interspaces between the stones and sand grains, and melting would not allow the drift to settle together to such an extent as to greatly diminish the height of the apparent embankment.

This conclusion is confirmed by phenomena seen at several points. In some cases small glaciers which had the habit of making these terminal embankments have disappeared or retreated, and the embankments which they had constructed, remain. This is shown in Fig. 31, which represents the morainic embankment left by an extinct cliff glacier[1] on the north side of Herbert Island. Several similar embankments occur in the same region.

In no case was the total apparent embankment determined to be of ice-filled débris, but in one place glacier ice was seen 110 feet below the apparent top of the embankment, so that the

[1] For definition of cliff glaciers, see this JOURNAL, Vol. III, p. 888.

glacier ice certainly extended that far down into the débris. The ice seen at this point, and in other gorges in similar situations, was distinctly laminated or stratified, and the laminæ were much contorted, just as in the case of glacier ice. This is

FIG. 31.—A morainic embankment, left at the terminus of an extinct cliff glacier, north side of Herbert Island.

mentioned only as indicating that the ice which cements the débris is not ice formed by the freezing of water which has trickled down from above into the débris, though in some cases this may be the fact.

It is evident that the growth of an embankment would be chiefly at the very terminus of a glacier. It is here that advance motion ceases, and it is here that all the material brought down from above must stop. It is easy to see that the débris, or débris-filled ice (which for present purposes amounts to the same thing) under the end of the active ice, might easily become higher than the bed of the glacier above. The ice would then have to push the embankment forward, or rise up over it. This probably has something to do with the upturning of

the terminal layers of ice. The same explanation would apply to the lateral margins of a glacier, where the upturning, so far as due to this factor, should be less than at the end, as is the fact.

Superglacial material.— Apart from the débris which gathers on the surface of glaciers near their ends and edges, and apart from that which gathers on the surface of the ice-cap near its edge, superglacial drift is generally wanting on the Greenland ice. Except in situations just below nunataks, stony débris was not seen at any point on the surface of the Greenland ice-caps, whether main or local, more than a fraction (rarely so much as one-fourth) of a mile back from their edges. On the surface of differentiated glaciers débris was often seen on the surface farther back from their ends, but this, in general, was in the form of medial moraines, marking the approximate line of contact between confluent glaciers, or representing material derived from nunataks, or from elevations which projected well up into the ice, but not through it, and therefore did not constitute nunataks. Occasionally there was débris in the form of medial moraines along the anticlinal part of the structure of the ice, as shown in Fig. 24.

At the very edges of the ice-sheets, and at the ends and edges of the glaciers, and in the position of medial moraines, superglacial drift was abundant, but apart from these situations there was no superficial drift on either ice-caps or glaciers, except the small amount of dust which had reached its position by the help of the wind. The wind-blown dust diminishes in quantity with increasing distance from the edge of the ice-cap, and from the ends and edges of glaciers. It is generally inconspicuous a mile or two back from the edge of an ice-cap, and inconspicuous on glaciers at any point as much as two or three miles from the nearest land surface.

That the dust was of wind origin could not be doubted, since it was absolutely free from all material which might not be readily transported by the wind, and did not affect the ice except at its surface. Furthermore, it contained, not infre-

quently, the leaves and twigs of the little shrubs which grow on the land in the vicinity.

The general absence of superglacial material on the ice-caps and glaciers of Greenland, except in situations in which débris has always been known to occur on glaciers, would seem to put an end to the doctrine which has been given currency in certain quarters that glacial débris in large quantities rises through the ice and gets upon its surface; for if the ice-cap of Greenland is free from superficial débris—except at its very margin—it would seem that the same should be still more conspicuously true of an ice-sheet on a plainer country, like our own. It is believed, however, that the phenomenon of the upturning of the layers of the ice at the edge of an ice-sheet would hold in a flat region, as well as in a mountainous one, especially where the ice was well charged with débris in its lower parts, and that this upturning would give rise to superficial drift for a few yards, or possibly a few hundred yards, back from the edge of the ice.

The disappearance of the doctrine of superglacial drift, as a general phenomenon, carries with it, of necessity, the doctrine that kames and eskers are the product of superglacial waters. On this point it should be further said that hundreds of superglacial streams, long and short, were seen on the ice-cap and on the glaciers of North Greenland, and with a single exception there was no material whatsoever accumulating in their channels. Except within the limits noted there was no drift upon the ice which the surface streams could not get hold of, nor, except at its very margins, was there drift in the ice down to the level to which the streams cut. Furthermore, the streams are almost uniformly so swift that no drift could accumulate in their channels unless it were extremely abundant on the surface. Every considerable stream seen on the ice had so high a velocity, and so smooth a bed, that even bowlders of considerable size would have been hurried along it precipitately, had they once entered the channel.

In the single case in which débris was seen in a superglacial stream channel, the amount was small and the conditions pecul-

iar. The stream was within a quarter of a mile of the edge of the ice, and flowing over the upturned edges of unequally hard layers of ice, which in their upturning had brought abundant débris to the surface. The harder layers stood up as little ridges, ponding the water above them and producing rapids below. In this stream there were trivial patches of gravel in the ponded portions. Even here there was nothing to suggest the development of an esker or a kame. There seems, therefore, to be no warrant in the phenomena of North Greenland, so far as known, for the belief either that there is, or can be, much superglacial till, or that superglacial streams can do much in the way of depositing stratified drift.

Physical and chemical condition of superglacial material.—The statement has often been made that superglacial material is highly oxidized and weathered, and that, on the basis of these characteristics, it may be distinguished from subglacial material, even in the drift deposits of the United States. This has been repeatedly cited as a criterion for the recognition of superglacial drift. This point was in mind during the study of the glacial phenomena of Greenland, and it may be emphatically stated that the superglacial drift of that land is not noticeably more oxidized and weathered than the subglacial. Where superglacial drift occurs, it appears to be as fresh, and its elements as firm in every way, as the subglacial material to be seen but a few rods away.

Lack of wear has been thought to be a mark of superglacial, as distinct from subglacial, bowlders. But the superglacial drift seen was often, though not always, as distinctly and thoroughly worn as the subglacial. This never appeared to be true where the superficial material arose from a nunatak, or from a hill or a mountain which just failed of being a nunatak, but it was generally true where the material on the surface had been brought up from the bottom by the upturning layers.

Glacial drainage.— Another striking feature of the north Greenland glaciers is the fact that the drainage from them does not behave altogether as drainage from glaciers is commonly supposed to. In the first place it is the rare exception that a

visible stream of any size issues from beneath a glacier at its end. That water really issues from the end of the glacier and flows on beyond can hardly be doubted, but in general it escapes beneath or through débris, rather than over it. In some cases, indeed, in crossing the embankment slope in front of the end of a glacier the motion of the water in the drift beneath one's feet can be heard.

As before noted, the sides of a glacier rarely rest against the valley in which the ice-stream lies, and in the gorge between the ice on the one side, and the valley wall on the other, there is usually a stream. These lateral streams are tolerably constant accompaniments of the glaciers, as Chamberlin has already pointed out.

Surface ablation does not give rise to many considerable streams on the surface of the ice. The surface is usually so crevassed that the water plunges beneath it soon after its formation, and the stream which continues for more than a few rods on the surface is the exception rather than the rule. Cases were however seen where superficial streams were continuous for some miles. The longest seen was on the surface of the largest glacier on the north side of Herbert Island. Here, in the summer of 1895, a stream was essentially continuous from the head of the differentiated portion of the glacier to a point near its terminus.

Englacial drainage does not show itself so long as the drainage is englacial, but the fact of englacial drainage was shown at several points. The most conspicuous example seen is shown in the accompanying figure, which represents the end of a large glacier on the south side of Olriks Bay. Here, as will be seen, a huge spout of water issued from about the middle of the vertical face at the end of the glacier. The diameter of the stream as it issued from the ice was about five feet. Issuing approximately horizontally, it showed that there was an englacial stream of similar proportions behind it. In such a case there is of course no means of knowing the length of the englacial stream, or how nearly it maintains its horizontal position. The

force with which the water shot out, in this particular instance. indicated plainly enough that it was under great head. In this case the stream was very red, due to the fact that it contained much sediment, or rock flour, arising from the comminution

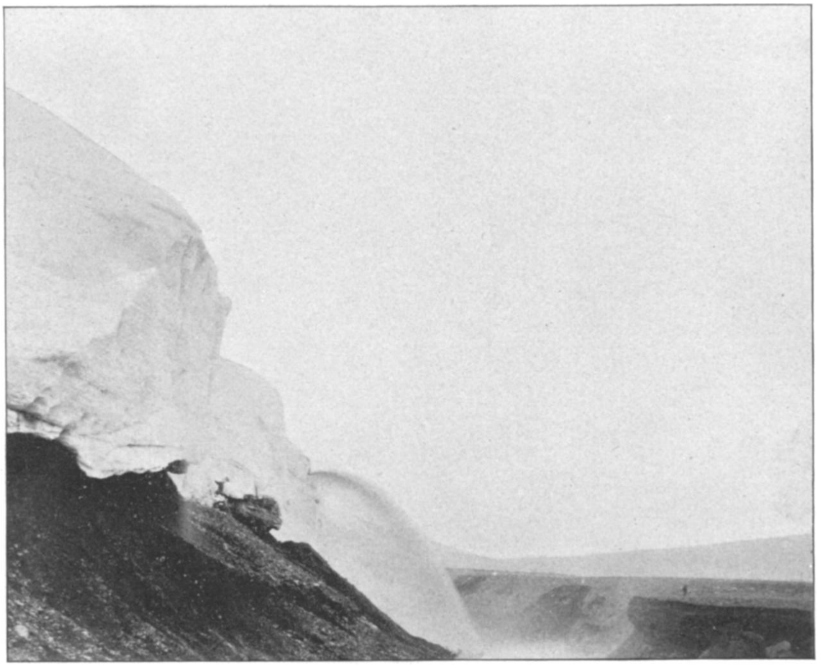

FIG. 32. End of the large glacier on the south side of Olriks Bay. Englacial stream issuing.

of the red rock over which the ice had moved. Since the stream issued from the ice at a level quite above any considerable amount of débris, it would appear that somewhere in its course the water must have been at a relatively lower level in the ice, flowing, throughout a portion of its course, sufficiently near the bottom of the glacier to acquire the silt which it contained.

That englacial water sometimes does flow under great pressure was shown by a phenomenon seen on one of the glaciers near Godhavn on the island of Disco. Here from the upper

surface of the glacier there welled up a huge spring (Fig. 33). The water shot up not less than ten feet above the bottom of the basin whence it issued. The water was intensely red, owing to the presence of the flour of red rock which the ice had ground

FIG. 33. Spring on the first glacier in the valley above Godhavn, Disco.

up. The upper part of the ice was nearly free from débris, and the water must have risen from a lower horizon in the ice. The inconstant character of englacial drainage is shown by the fact that two months later, at the same site, there was no suggestion of a spring. The water had found some other avenue of escape, though the basin and the opening in its bottom were easily found. The opening was about five feet in diameter, and for a distance descended nearly vertically.

Kames and eskers.—No esker was seen in Greenland, nor was any process observed which would at any time result in the formation of an esker.

Except in one situation, namely, on the north side of Olriks Bay, no kame was seen. Here there were some kame-like hills on a surface which had been abandoned by the ice, but no process was seen in operation along the margin of the ice at any point which seemed to throw special light on the origin of this class of drift hills.

The surface over which the ice has retreated.—In a number of places, surfaces were seen which have been, within relatively

recent times, covered by the ice, but which are now free from it. Such surfaces were seen on the Redcliff peninsula, and on the peninsula east of Bowdoin Bay; but in no case where the abandoned surface was seen did it appear to be true that its topography was fashioned by the drift. The main features, at least where there were roughnesses, seemed to be due to the underlying rock, and the effect of the drift, on the whole, was rather to level the surface than to roughen it. In general the topography of the drift on surfaces abandoned by ice-sheets, so far as it could be differentiated from the topography of the underlying rock, was nearly plane.

There were, however, minor details of surface which were notable. It was frequently to be seen that the drift of a surface recently abandoned by the ice was disposed in a multitude of tiny crescentic ridges, concave toward the ice. The ridges were one to ten feet wide, and one to ten yards long. They were generally no more than one or two feet high, and just within the crescent there was likely to be a depression of perhaps an equal amount, so that the generally flat surface still had a relief of two to four feet. This was perhaps the most conspicuous minor detail observable on the surface of the drift. Much of the drift-covered surface of the flat uplands looked as if a heavy roller had been passed over it. Much of the surface which had been recently freed from ice was essentially without relief.

On the whole, the drift in Greenland is notably more stony than the drift of our own country. Clay, due to the grinding of the rock, was everywhere conspicuous by its paucity or absence.

ROLLIN D. SALISBURY.